National Aeronautics and Space Administration

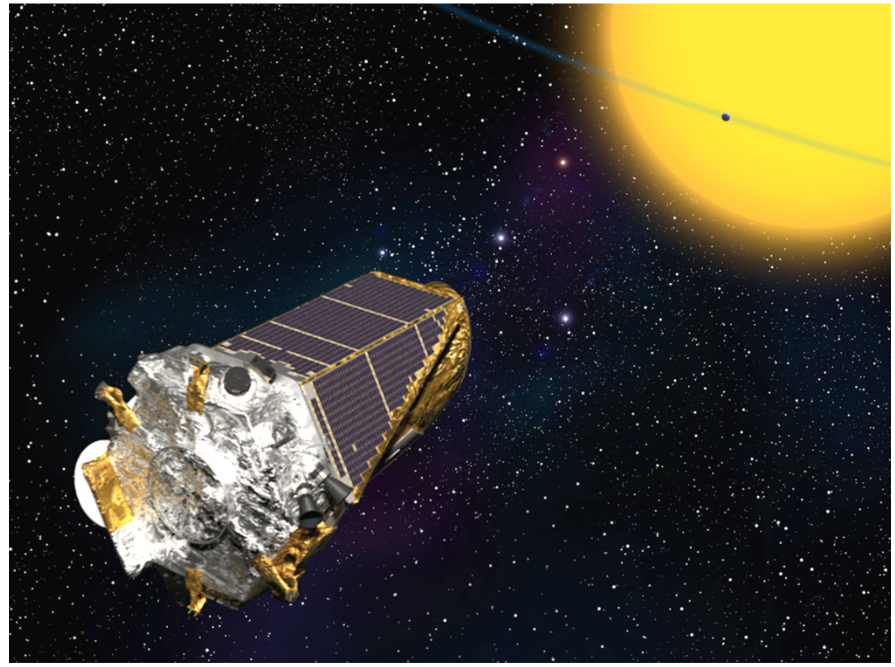
Kepler Mission Development Challenges and Early Results

IEEEAC paper #1367

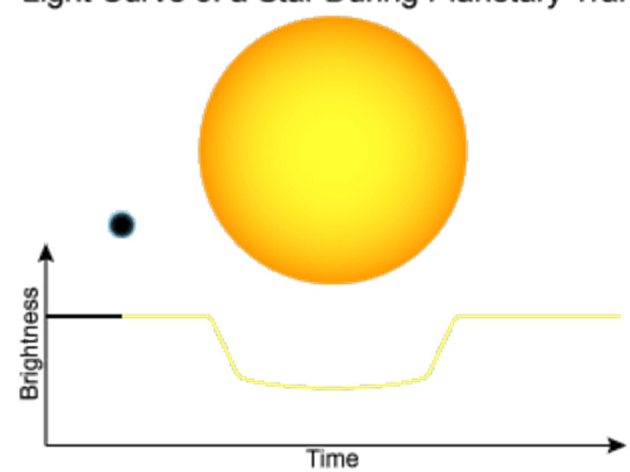
James Fanson, Ph.D.
Margaret Frerking, Ph.D.
Riley Duren
Jet Propulsion Laboratory
California Institute of Technology

Kepler is NASA's first mission capable of detecting Earth-size planets orbiting in Habitable Zone of Sun-like stars

- Objective is to measure how frequently planets of various sizes and orbits form around stars in the Milky Way
- Kepler detects planets by measuring drop in brightness of star due to "transit" of a planet
- Earth-size planet transiting Sun-like star causes drop in brightness of only 84 parts per million (very hard to measure!)
- Only ~1% of planetary orbits will be aligned to produce transits (requires large number of targets, and large field of view)
- One transit per orbit (requires mission of at least 3½ years)

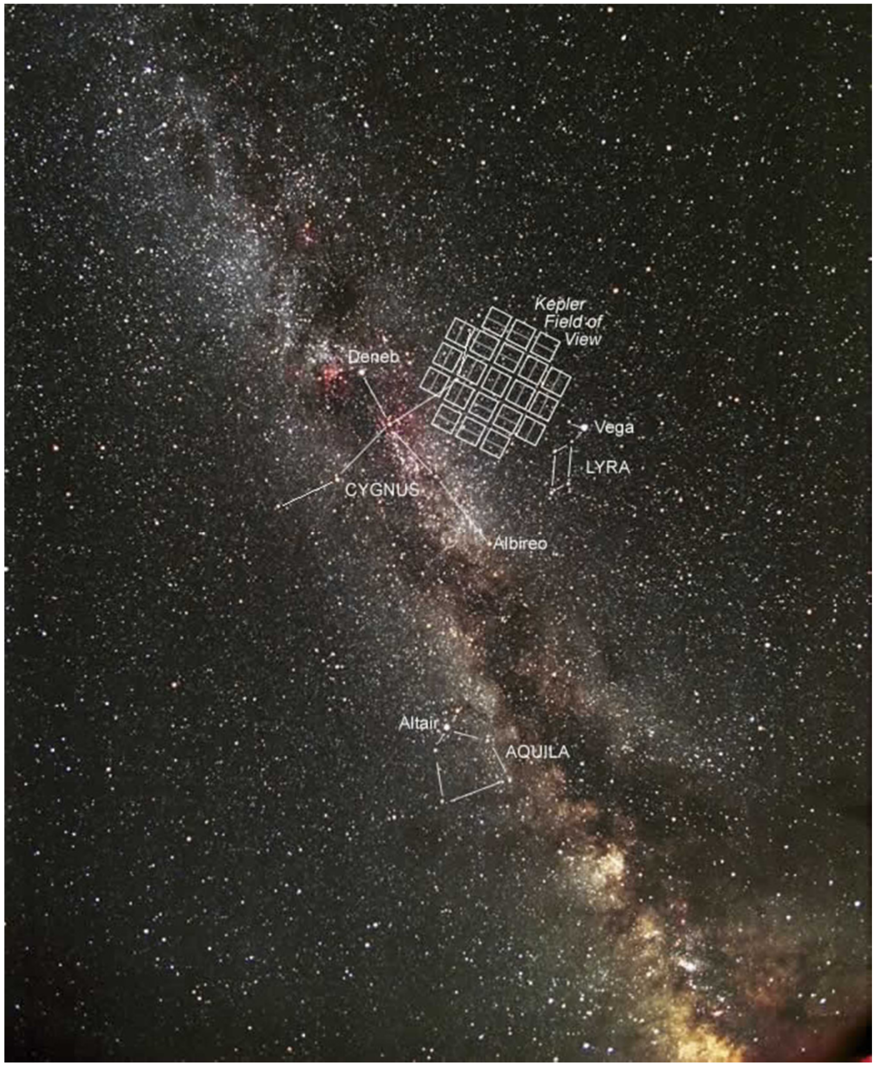


Light Curve of a Star During Planetary Transit



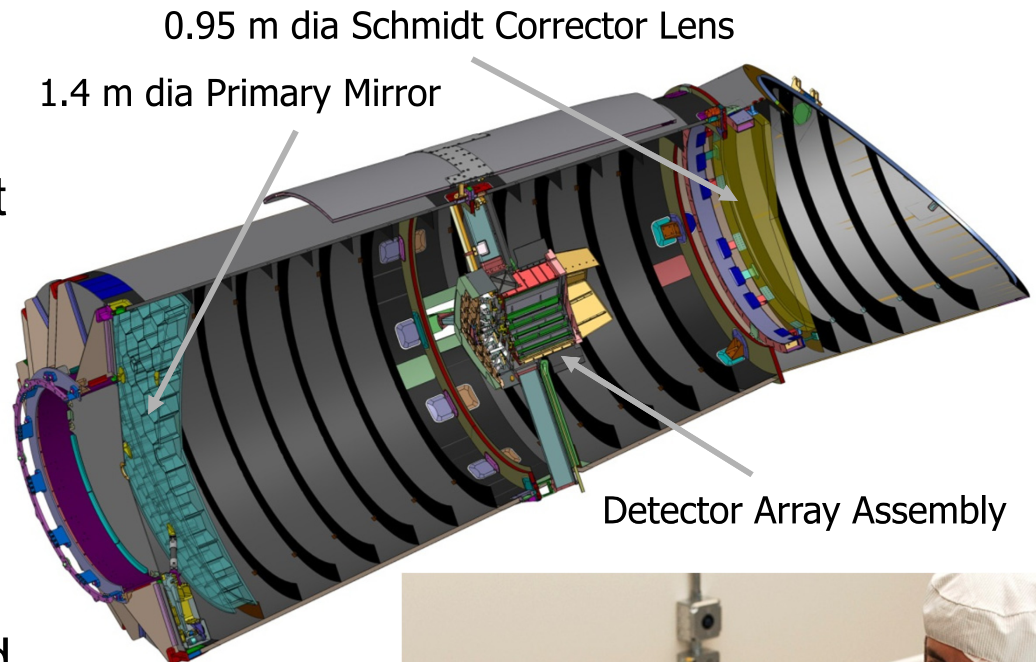
Kepler observes a single 100 square degree field of view in the constellation Cygnus

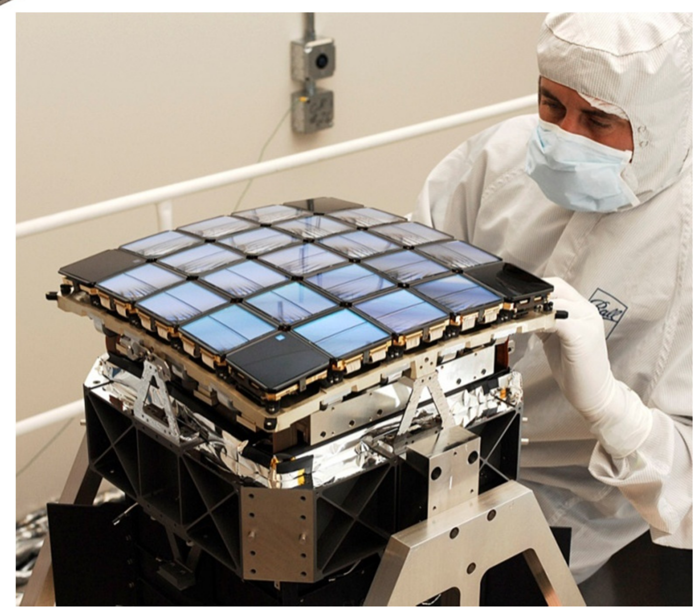
- Earth-trailing heliocentric orbit permits continuous viewing all year round
- Target list includes >150,000 most sun-like stars
- Simultaneous brightness measurements made every 30 minutes
- Data returned to Earth once per month



Kepler is an extremely sensitive photometer

- Required photometric precision is 20 ppm
- Stellar variability is greatest single uncertainty (Sun varies at 10 ppm)
- Technologies mature, but system is large and complex, and photometric performance requirement unprecedented
- Controlling noise sources and systematic errors, and validating photometric performance were the main challenges





Performance is often at odds with reliability

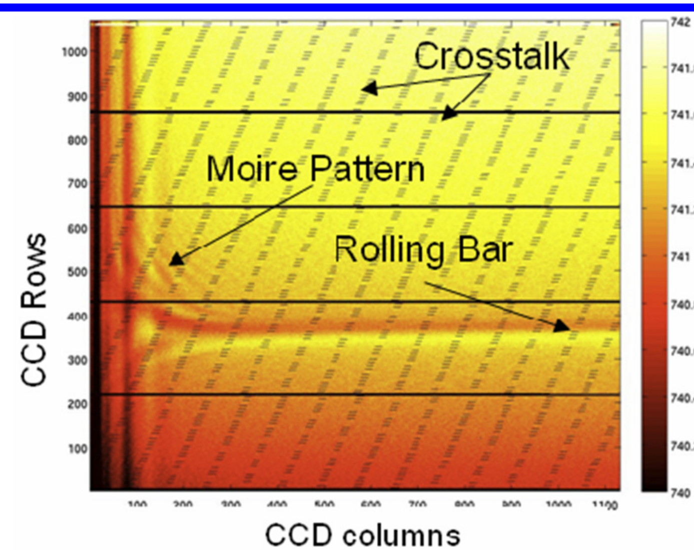
- Focal plane is large (95 megapixels) and readout electronics must provide: high readout, good well depth & linearity, low noise and power
  - Unique components selected, including >100 Intersil EL7457 quad CMOS clock drivers
  - Good performance, but:
    - Late discovery that EL7457 operated at 13-15 volt bias susceptible to catastrophic failure from single event effects
    - Prior radiation screening used facility with inadequate energy beam
    - Flight electronics boards, as already manufactured, posed unacceptable risk
  - Testing at alternate facility established most likely failure mode to be Single Event Latchup (SEL)
    - Design was modified to operate at 11.75 volts by replacing ~200 resistors
    - Contributed to systematic noise sources (more on that later)
    - Project schedule significantly impacted, but mission successful due to vigilance of Ball Aerospace radiation effects engineer

End-to-end performance testing is sometimes not practicable

- Concepts to test photometric performance and demonstrate Earth-size transit capability on final flight system proved impracticable
- Layered approach used instead (this always requires great care)
  - Camera-level testing under cold conditions
  - Photometer focus and point-spread function (PSF) testing
  - Single-string transit verification testbed
  - Analysis modeling to synthesize test results with missing noise sources, such as pointing jitter
- A “bottom-up” noise estimate was compared with “top-down” estimate

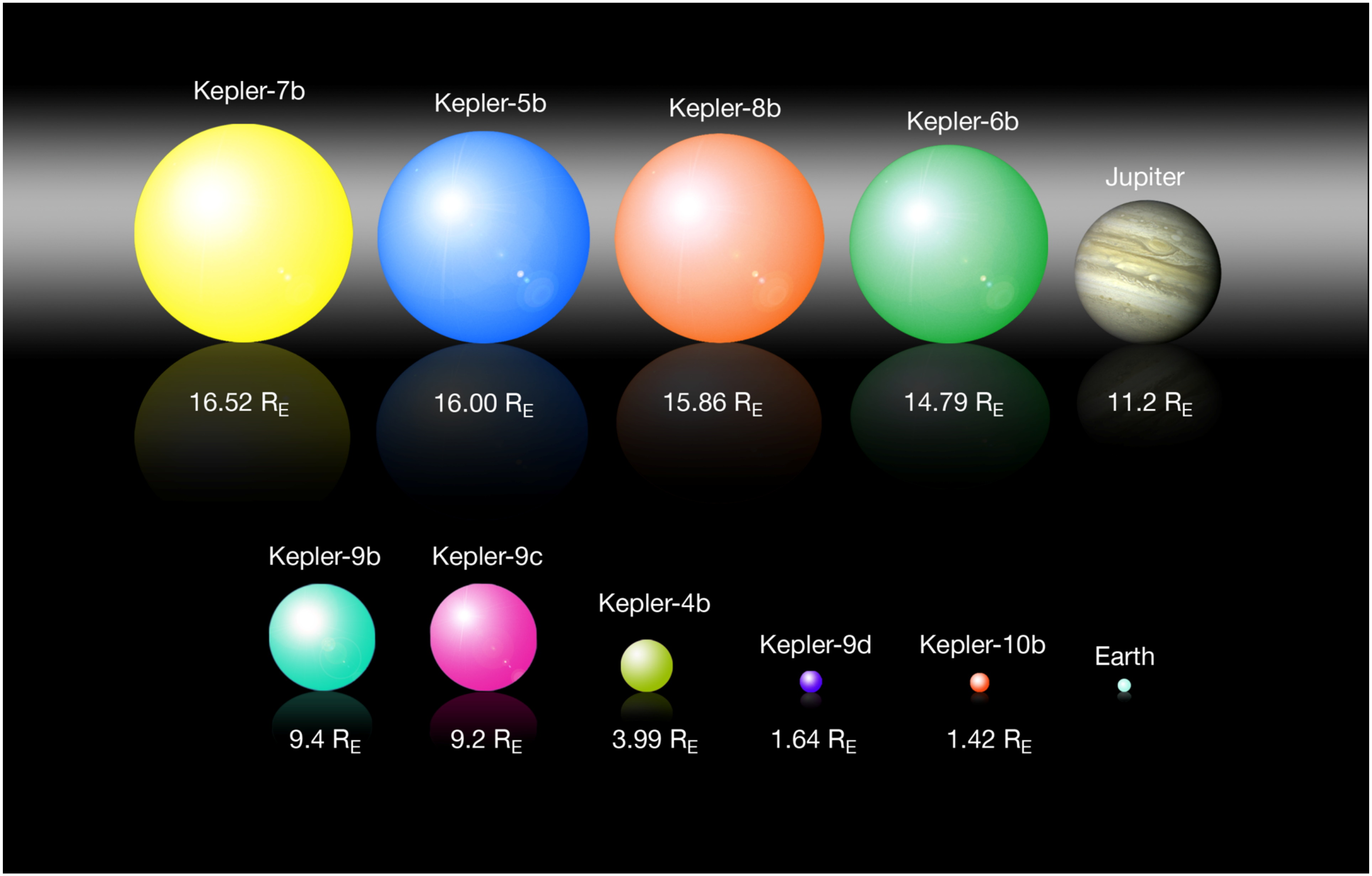
When you're at new levels of performance, test-like-you-fly exceptions can mask important effects

- Control and calibration of systematic noise was critical to Kepler performance
  - Several issues, some traceable to the very compact DAA at telescope prime focus, led to design compromises
  - Characterizing effects proved difficult as some were temp dependent and masked by test conditions, others nonlinear
    - Principal sources are 1) cross talk between 42 science and 4 FGS CCDs, and 2) high frequency, low level oscillations in 33 of 84 readout electronics channels

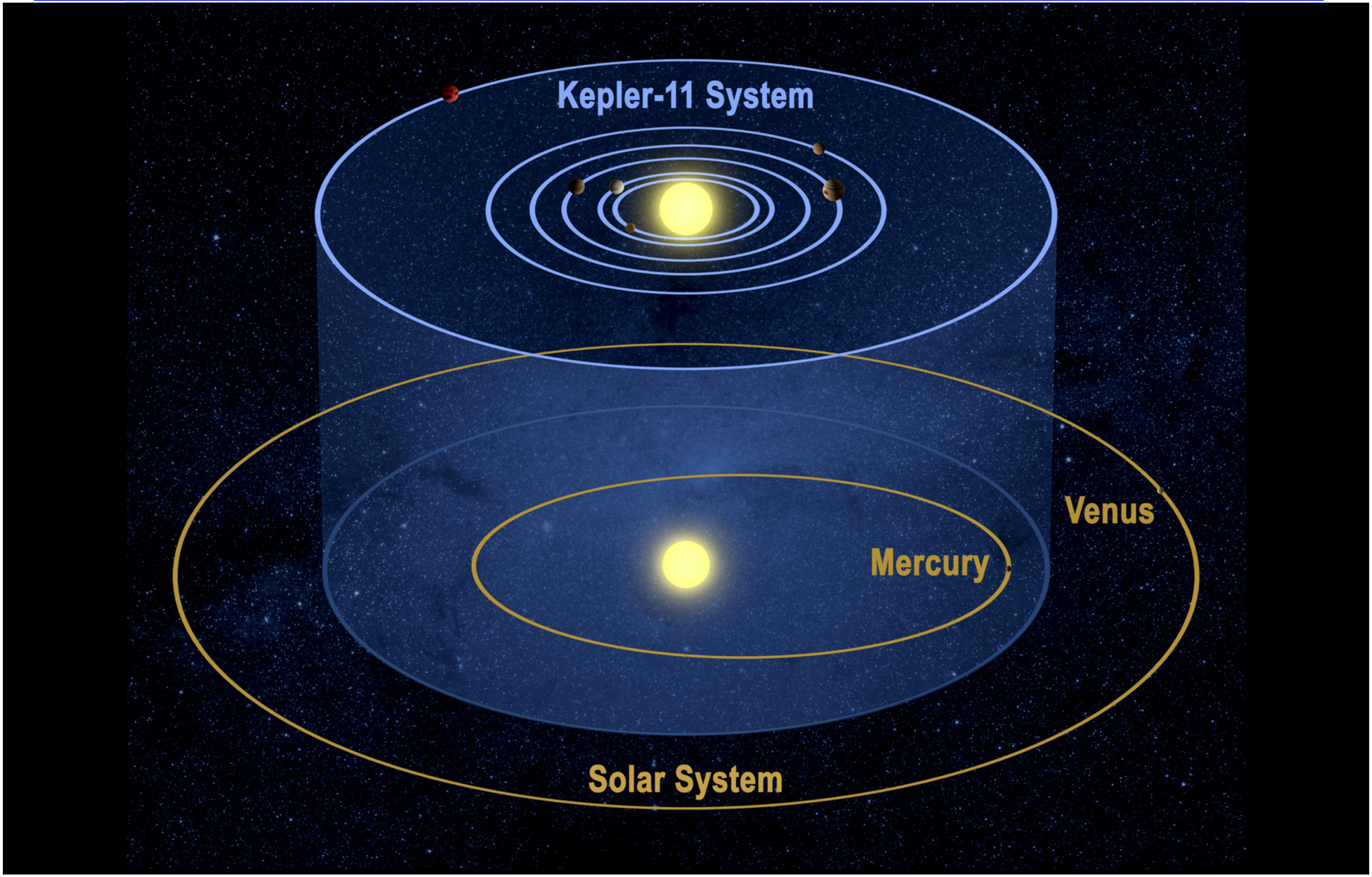


- Test program was rigorous, and progressively more flight-like at ever higher levels of assembly
  - Increasing temperature stability caused temp-dependent effects to more closely emulate planet transits! Calibration by simple subtraction ineffective
- Some portions of field of view therefore have lower sensitivity
  - Complex calibration required, resulting in operations software development challenges

Hard work and attention to details pays off



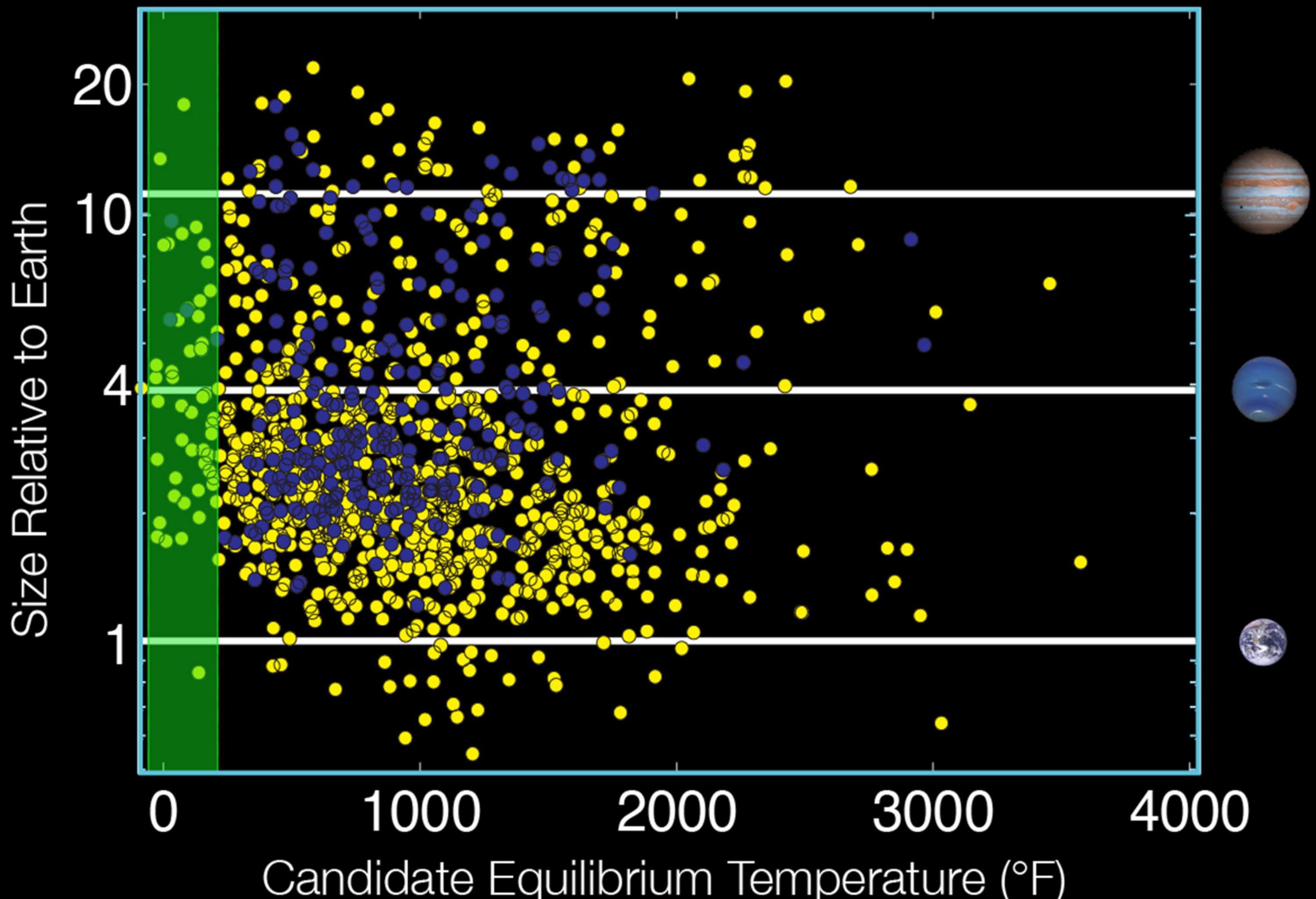
15 planet discoveries have been confirmed and announced, including six-planet system Kepler-11



But this is just the beginning of many discoveries to come

(follow the adventure at http://kepler.nasa.gov/Mission/discoveries)

- Planet candidates as of 1 Feb 2011



NASA